

PREFACE xiii

CHAPTER 1 **FOURIER SERIES AND TRANSFORMS** **1**

- 1.1 The Definition of the Fourier Series **1**
- 1.2 Examples **4**
- 1.3 Properties of the Fourier Series **11**
- 1.4 Applications of Fourier Series **14**
- 1.5 From the Fourier Series to the Fourier Transform **24**
- 1.6 Theorems of the Fourier Transform **29**
- 1.7 The Fourier Transform of Power Signals **39**
- 1.8 The Poisson Sum Formulas **44**
- 1.9 Time-Averaged Autocorrelation Functions and Power Spectral Density for Periodic Signals **46**
- 1.10 The Sampling Theorem and Applications **49**
- Problems **57**
- References **62**

CHAPTER 2 **SPECTRAL ANALYSIS OF DATA SIGNALS AND NOISE** **63**

- 2.1 The Elements of Probability Theory **63**
- 2.2 Probabilities of Multiple Random Variables **71**
- 2.3 Gaussian Probability Density Functions **72**
- 2.4 The Briefest Possible Review of Random Processes **75**
- 2.5 Data Signals: Power Spectral Density and Autocorrelation Function **80**
- 2.6 How Coding Changes the Power Spectral Density of Data Signals **83**
- 2.7 The Power Spectral Density of a Markov Process **86**
- 2.8 The Gaussian Random Process **95**
- 2.9 Transmission of Random Signals Through Linear Systems **98**
- 2.10 Band-Limited Gaussian Noise **103**
- 2.11 An Application: Spectral Line Timing Recovery **104**
- 2.12 Forward-Acting Carrier Recovery **110**

APPENDIX 2A **TABULATION OF $Q(x) = \int_x^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\alpha^2/2} d\alpha$** **112**

- Problems **113**
- References **115**

CHAPTER 3 **BASEBAND DATA TRANSMISSION** **116**

- 3.1 Transmitting and Receiving a Data Signal **116**
- 3.2 Computing the Probability of Error **119**

- 3.3 Minimizing the Probability of Error With an RC Receiver Filter **120**
- 3.4 The Optimum Receiver Filter—The Matched Filter **121**
- 3.5 Continuous Data Streams and Intersymbol Interference (ISI) **125**
- 3.6 The Correlation Receiver **126**
- 3.7 A DSP-Oriented Receiver Structure **128**
- 3.8 Multilevel Signaling With a Matched Filter Receiver **129**
- 3.9 Bandlimited Channels and Nyquist Signaling **131**
- 3.10 Examples of Baseband Data Transmission **136**
- 3.11 Equalization, Noise Amplification, and Intersymbol Interference (ISI) **140**
- 3.12 The Eye Pattern **142**
- 3.13 Intersymbol Interference as a Markov Process **143**
- 3.14 Partial Response Signaling **144**
- 3.15 Magnetic Recording and Partial Response Signaling **153**
- 3.16 Higher-Order Partial Response Systems for Magnetic Recording **157**
- 3.17 Decision Feedback Detection of Partial Response Signals **158**
- 3.18 Scramblers **159**
 - Problems **162**
 - References **163**

CHAPTER 4 ***BANDPASS DATA TRANSMISSION*** **166**

- 4.1 The Basic Structure of Quadrature Amplitude Modulation (QAM) **166**
- 4.2 Differential Coding of QAM Signals **171**
- 4.3 Some Telephone Line Modem Examples **176**
- 4.4 Bandpass Signals and Noise **179**
- 4.5 Implementation of the Hilbert Transform Receiver **187**
- 4.6 The Baseband Equivalent of a Bandpass System **191**
- 4.7 OQPSK (Offset QPSK) and MSK (Minimum-Shift Keying) **196**
- 4.8 Differential Phase-Shift Keying (DPSK) **200**
- 4.9 Digital Microwave Transmission **202**
- 4.10 Multicarrier Data Transmission **203**

APPENDIX 4A ***COMPUTER MODELING OF THE BASEBAND EQUIVALENT OF A QAM MODEM*** **213**

- 4A.1 The Scrambler-Descrambler Pair **214**
- 4A.2 QPSK Modulator-Demodulator **215**
- 4A.3 16-QAM Modulator-Demodulator **217**
- 4A.4 Carrier Phase Impairments **220**
- 4A.5 Additive Noise **221**
 - Problems **222**
 - References **224**

CHAPTER 5 ***MAXIMUM LIKELIHOOD SIGNAL DETECTION AND SOME APPLICATIONS*** **226**

- 5.1 Vector Spaces and Function Spaces **226**
- 5.2 Eigenvalues and Eigenvectors **233**
- 5.3 Representation of Signals and Additive White Gaussian Noise **237**

- 5.4 The Correlation Receiver in the Presence of Additive White Gaussian Noise **240**
- 5.5 Probability of Error for M-ary Orthogonal and Simplex Signaling **250**
- 5.6 The Matched Filter Receiver in the Presence of Non-White Gaussian Noise **255**
- 5.7 Representation of Non-White Gaussian Noise: The Karhunen-Loeve Expansion **256**
- 5.8 Maximum Likelihood Sequence Estimation (MLSE) **259**
- 5.9 Noncoherent Detection of Bandpass Signals **268**
- 5.10 Continuous Phase Modulation **271**
Problems **276**
References **279**

CHAPTER 6 *CARRIER PHASE AND TIMING RECOVERY* **281**

- 6.1 The Classic Phase-Locked Loop **281**
- 6.2 Noise in the Classic Phase-Locked Loop **287**
- 6.3 Maximum-Likelihood Carrier-Phase Estimation **288**
- 6.4 A Decision-Directed Adaptive Rotator **298**
- 6.5 A Sampled-Data PLL for Implementing an Adaptive Rotator **302**
- 6.6 Noise and Carrier-Phase Jitter in Sampled-Data Carrier-Phase Recovery Loops **309**
- 6.7 Software Implementation of the Adaptive Rotator **312**
- 6.8 Maximum Likelihood Timing Recovery **313**
- 6.9 Baud-Rate Timing Recovery **317**
- 6.10 Timing Recovery for QAM Systems With Baud-Rate Equalization **319**
Problems **324**
References **325**

CHAPTER 7 *CHANNEL MODELS FOR COMMUNICATION SYSTEMS* **327**

- 7.1 A Recapitulation of the Baseband Equivalent Channel Model **327**
- 7.2 The Ordinary Telephone Line **330**
- 7.3 Twisted Pair and Coaxial Cable **335**
- 7.4 Multipath and Rayleigh Fading Channels **340**
Problems **350**
References **351**

APPENDIX 7A *ATTENUATION AND DELAY CHARACTERISTICS OF THE ORDINARY TELEPHONE LINE* **353**

CHAPTER 8 *CHANNEL CAPACITY AND CODING* **357**

- 8.1 Introduction **357**
- 8.2 Channel Models **358**
- 8.3 Channel Coding for Error Reduction **359**
- 8.4 The Noisy Channel Coding Theorem and Channel Capacity—A First Look **361**

- 8.5 Information, Entropy, and Channel Capacity **366**
- 8.6 The Capacity of an Ideal Bandlimited Channel Having AWGN **370**
- 8.7 The Capacity of an Arbitrary Waveform Channel Subject to a Power Constraint **374**
- 8.8 The Capacity of Some Common Channels **378**
- 8.9 Exponential Error Bounds for Rates Below Capacity **380**
- Problems **386**
- References **386**

CHAPTER 9 *TRELLIS CODING AND MULTIDIMENSIONAL SIGNALING* **388**

- 9.1 Block Coding and Convolutional Coding **388**
- 9.2 Introducing Trellis Codes **391**
- 9.3 Rotationally Invariant Trellis Codes **400**
- 9.4 Multidimensional Signaling and Optimum Signal Constellations **406**
- 9.5 Multidimensional Trellis Codes **410**
- 9.6 Trellis Codes for PSK Systems **410**
- 9.7 A Final Note on References **411**
- Problems **411**
- References **412**

CHAPTER 10 *EQUALIZATION OF DISTORTED CHANNELS* **414**

- 10.0 Introduction **414**
- 10.1 Transversal Symbol-Rate Equalizers for Baseband and Bandpass Channels **415**
- 10.2 The Optimum Linear Receiver **427**
- 10.3 The Fractionally Spaced Equalizer **435**
- 10.4 Wiener Filtering and the Wiener-Hopf Equation **439**
- 10.5 Decision-Feedback Equalization **443**
- 10.6 Suboptimal Decision-Feedback Structures **454**
- 10.7 Comparing the Performance of Equalizer Structures **456**
- 10.8 Error Propagation in Decision-Feedback Equalizers **461**
- 10.9 Tomlinson-Harashima Precoding **464**
- 10.10 Optimum Signal Detection Using MLSE **467**
- Chapter 10 Problems **469**
- References **470**

CHAPTER 11 *ADAPTIVE EQUALIZATION AND ECHO CANCELLATION* **474**

- 11.0 Introduction **474**
- 11.1 The Gradient Algorithm for Equalizer Convergence **474**
- 11.2 The LMS Algorithm for Baud-Rate Equalizer Convergence **481**
- 11.3 The LMS Algorithm for Fractionally Spaced Equalizers **485**
- 11.4 The Relationship Between the Adaptive Rotator and the Adaptive Equalizer **490**
- 11.5 Software Implementation of the LMS Algorithm **492**
- 11.6 The RAM-DFE Decision Feedback Equalizer **495**

- 11.7 Equalizer Convergence for Partial Response Systems **496**
- 11.8 Cyclic Equalization **500**
- 11.9 The RLS (Recursive Least Squares) Algorithm for Equalizer
Convergence **504**
- 11.10 The Fast Kalman Algorithm for Channel Equalization **508**
- 11.11 Lattice Equalizers **513**
- 11.12 Adaptive Echo Cancellation **519**
 - Problems **526**
 - References **527**

INDEX 533